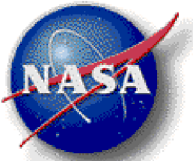


Determination of Tolerance to Internal Shorts and Its Screening in Lithium-ion Cells NASA - JSC Method

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Judith Jeevarajan/NASA-JSC



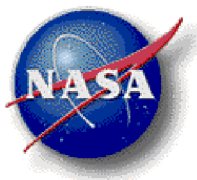
Internal Short Locations and Severity

Frank Zhao at 2007 IEEE PSES (Product Safety Engineering Society) Symposium presented the following data:

- Anode Film ↔ Cathode Film ($< 120^{\circ}\text{C}$)
- Anode Film ↔ Al Foil (thermal runaway)
- Cathode Film ↔ Cu Foil ($< 100^{\circ}\text{C}$)
- Al Foil ↔ Cu Foil ($< 80^{\circ}\text{C}$)

COTS Li-ion cells are produced in millions and if the quality control is not stringent, there is a higher possibility of getting internal cell shorts due to the presence of impurities such as metal particles, burrs, etc.

NASA is more concerned about the impurities manifesting an internal short by dislodging and piercing the separator, during launch.

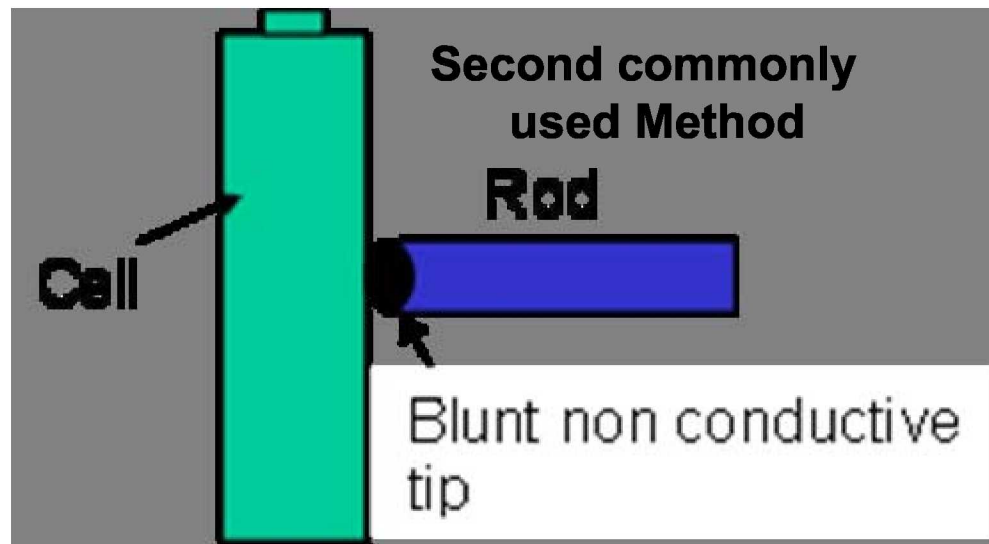
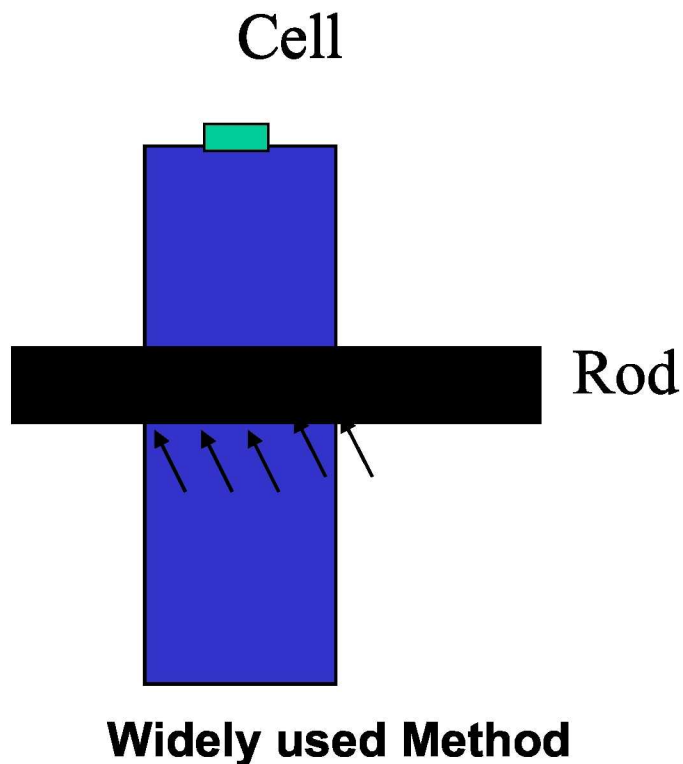


NASA –JSC Li-ion Battery History

- COTS li-ion batteries were first flown by NASA-JSC in 1999 – BP 927 Canon camcorder battery
- Since then several different COTS li-ion batteries have been flown for portable electronic equipment including laptops, camcorders, cameras, PDA, RFID, payload experiments, etc. – and under some of these categories several different models have been flown. Note: other equipment use the same batteries with adapters.
- In 1998, when we first looked into qualifying the li-ion batteries for flight, I was asked to identify a method to detect a cell's tolerance to internal shorts.
- I devised a simulated crush method that was perfected to provide consistent results.



Schematic for Test Setup





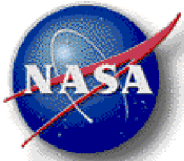
More History..

From 1998 to 2001, most li-ion cells tested, vented violently with expulsion of contents. But some instances of benign results were also encountered. It was determined that:

- **The results were dependent on the nature of the crush**
 - **Light or slow crushes did not cause significant venting.**
 - **Heavy and fast crushing caused significant venting with smoke and fire; sometimes thermal runaway.**



- **A specific set of conditions were formulated for this test.**



Determination of Cell Tolerance to Internal Shorts

Simulated internal Short tests are carried out in the following manner

- **Cells to be tested shall be at 100 % SOC; sample size depends on the lot size – a minimum of 3 cells per lot shall be tested.**
- **Voltage and Temperature shall be monitored throughout the test.**
- **Video recording shall be performed throughout the test.**
- **A rounded metal rod with a non-conductive tip of ¼ or 1/8” diameter shall be used to perform the simulated short. (insulating materials such as Kapton, teflon tape, teflon tips, etc. can be used – no heat dissipation through rod and no electrical path)**
- **The rod shall approach the cell perpendicular to the length of the cell, away from the terminals.**
- **The rate of crush will be approximately 19 psi/minute.**
- **The crush shall be carried out in such a way that there is only deformation without penetration.**
- **The crush shall be stopped as soon as the voltage falls to zero; changed recently to “fall in voltage by about 500 mV”.**



Interpretation of Results of Internal Short Test

- Cell chemistries that do not display a violent expulsion of contents, fire or thermal runaway are said to be tolerant to internal shorts. Electrolyte leakage is not considered as an intolerance.
- Cell chemistries that display a violent expulsion of contents, fire or thermal runaway are said to be intolerant to internal shorts.





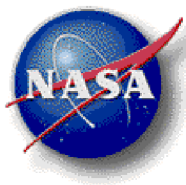
Sanyo Cobaltate Cell Simulated Internal Short





Simulated Internal Short - Cobaltate Cell

8B020_Crush_SN001_07_16_04.mov

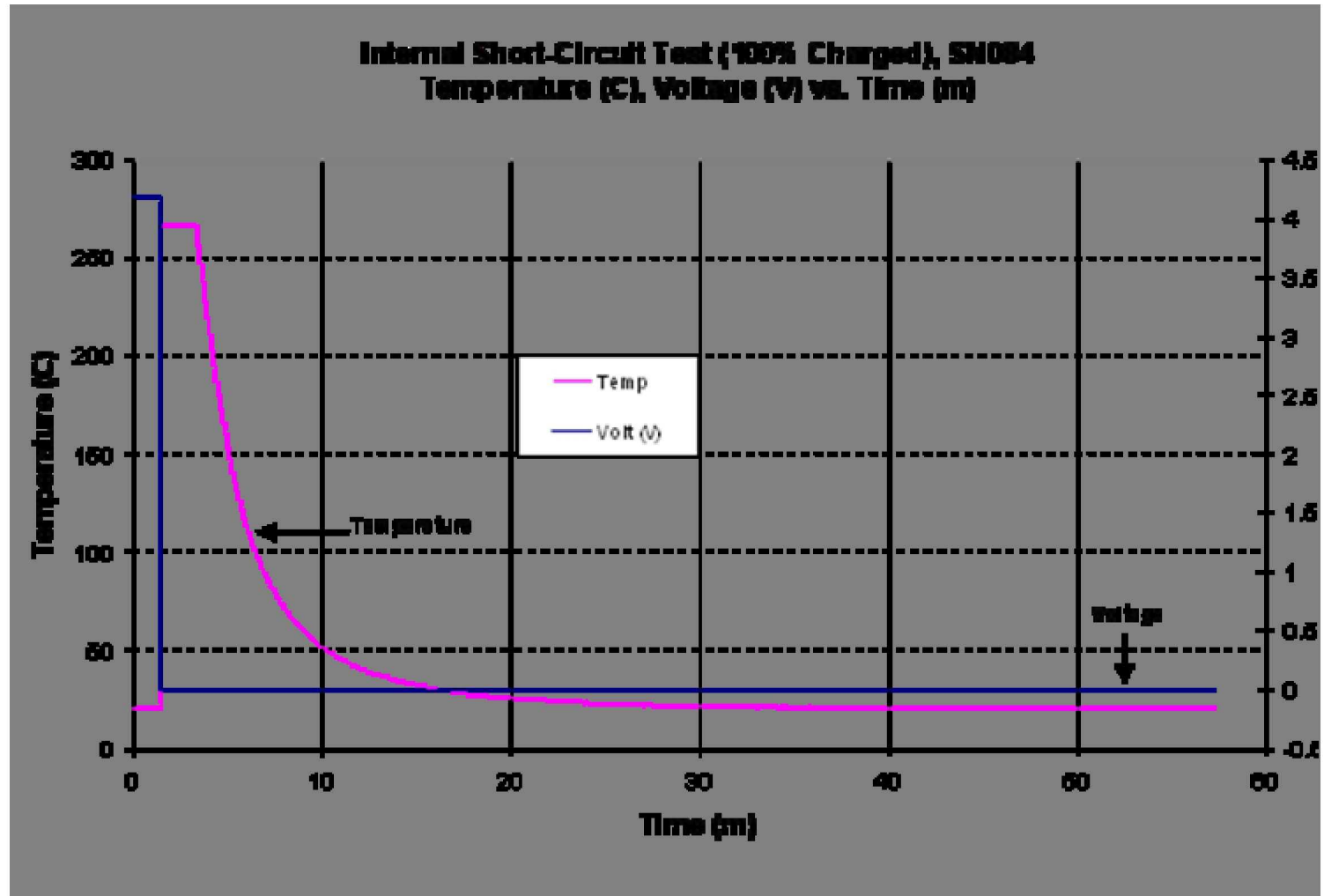


Moli 2.4 Ah Cobaltate Cell Simulated Internal Short-Circuit Test

Cell Serial Number	State of Charge (Ah)	Occurrence
082	100 %	Ignited Upon Crushing
083	100 %	Ignited Upon Crushing
084	100 %	Ignited Upon Crushing
085	50 %	None
025	50%	None
026	50%	None

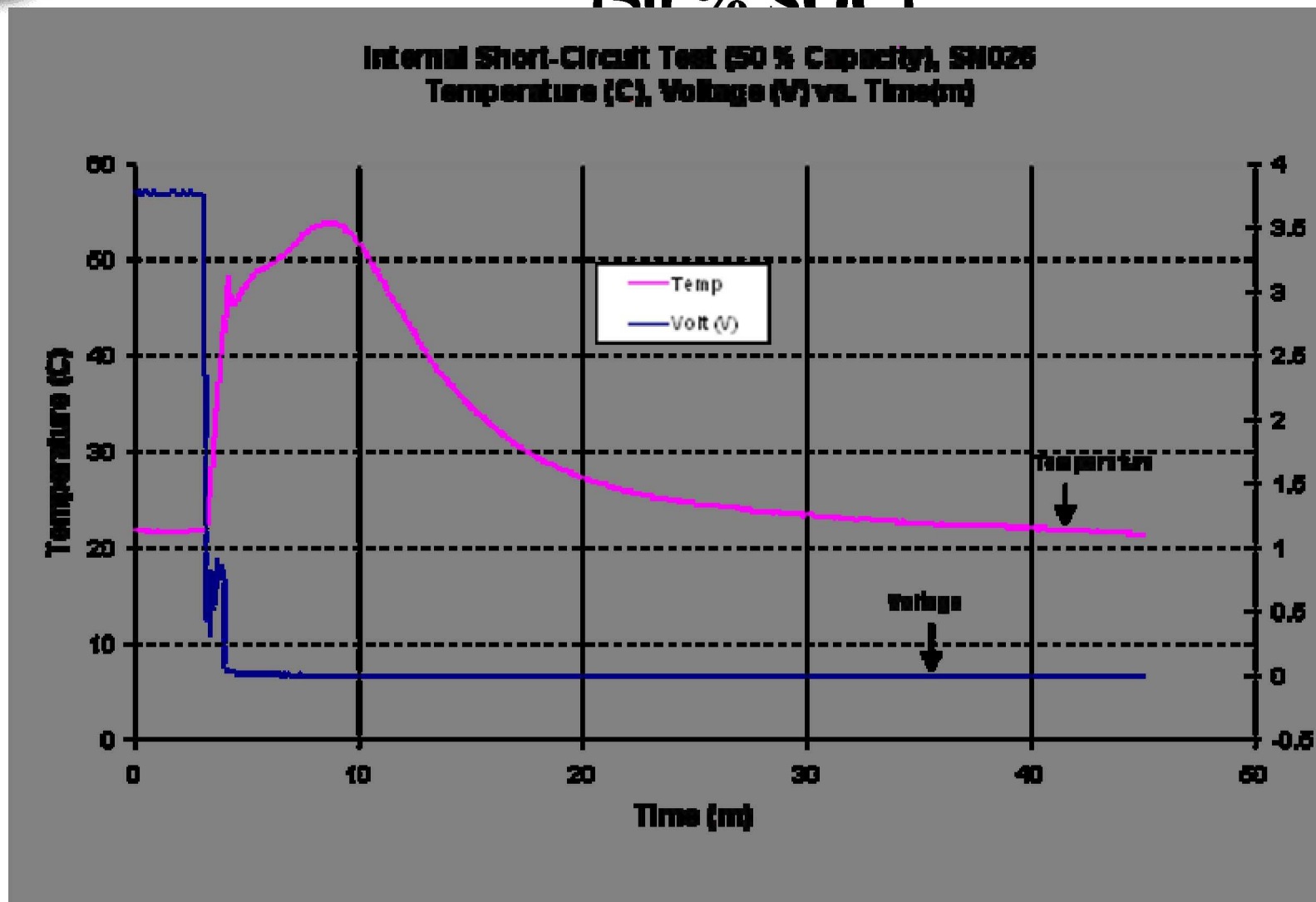


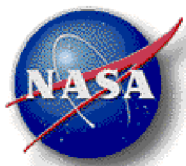
Moli 2.4 Ah Cobaltate Internal Short-Circuit Test (100 % SOC)



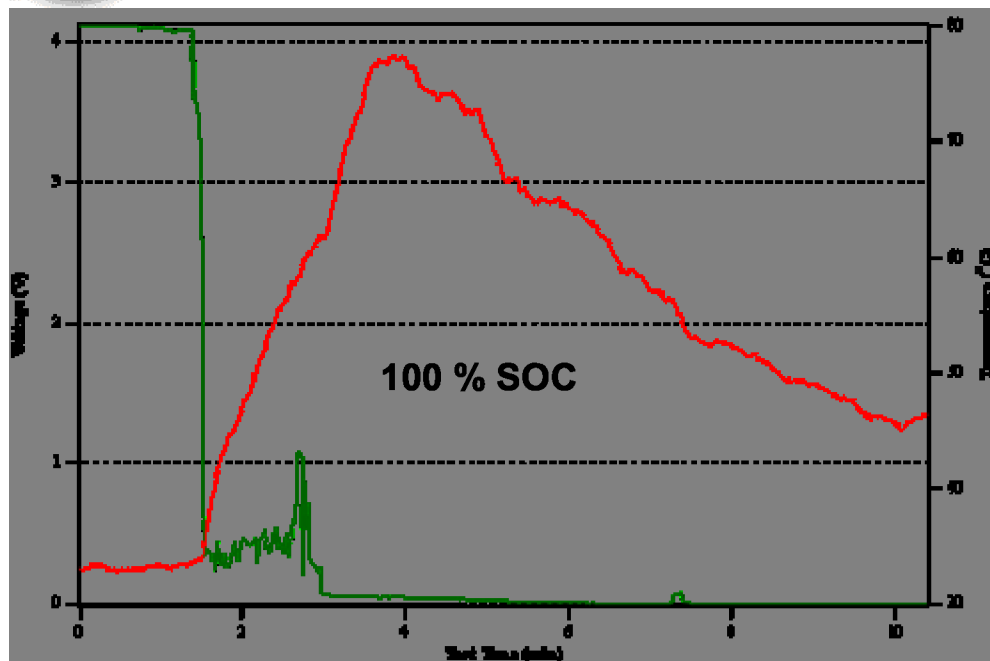


Moli 2.4 Ah Cobaltate Internal Short-Circuit Test (50 % SOC)





Moli 2.9 Ah Spinel Internal Short-Circuit Test Cell Performance



Cell SN	State of Charge	Pre Test Voltage	Final Results
082	100 %	4.138 V	No reaction
083	100 %	4.138 V	No reaction
084	50 %	3.936 V	No reaction
085	50 %	3.937 V	No reaction



Test setup

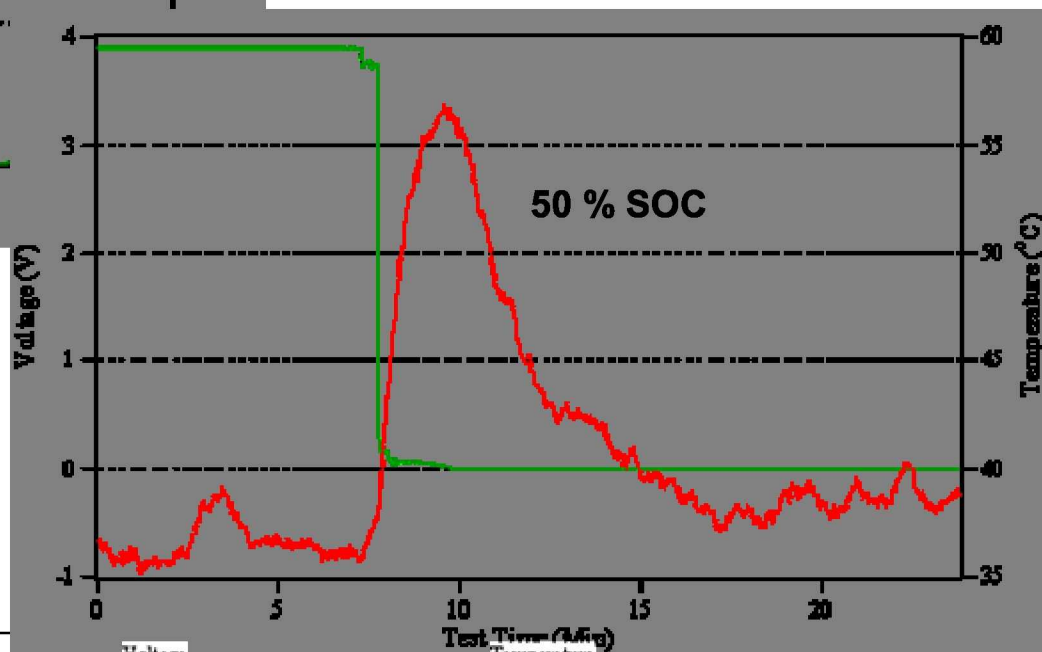
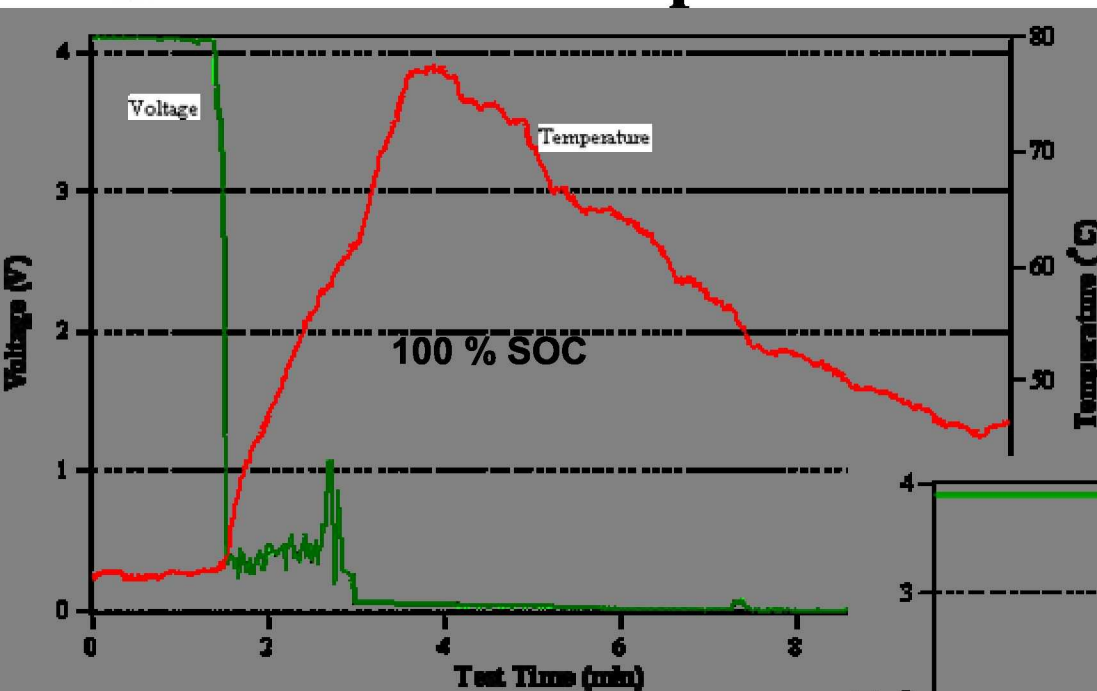
Simulated Internal Short/Crush Test on the Moli Spinel 18650 Li-ion Cells



**Fully charged cells: max temp: 77 °C
(electrolyte leakage; no venting or fire)
50 % charged cells: max temp: 57 °C (no
venting or fire)**



Simulated Internal Short/Crush Test on the Moli Spinel 18650 Li-ion Cells



Judith Jeevarajan/NASA-JSC



Simulated Internal Short Test on Li-ion Cell from a Safety R&D Program

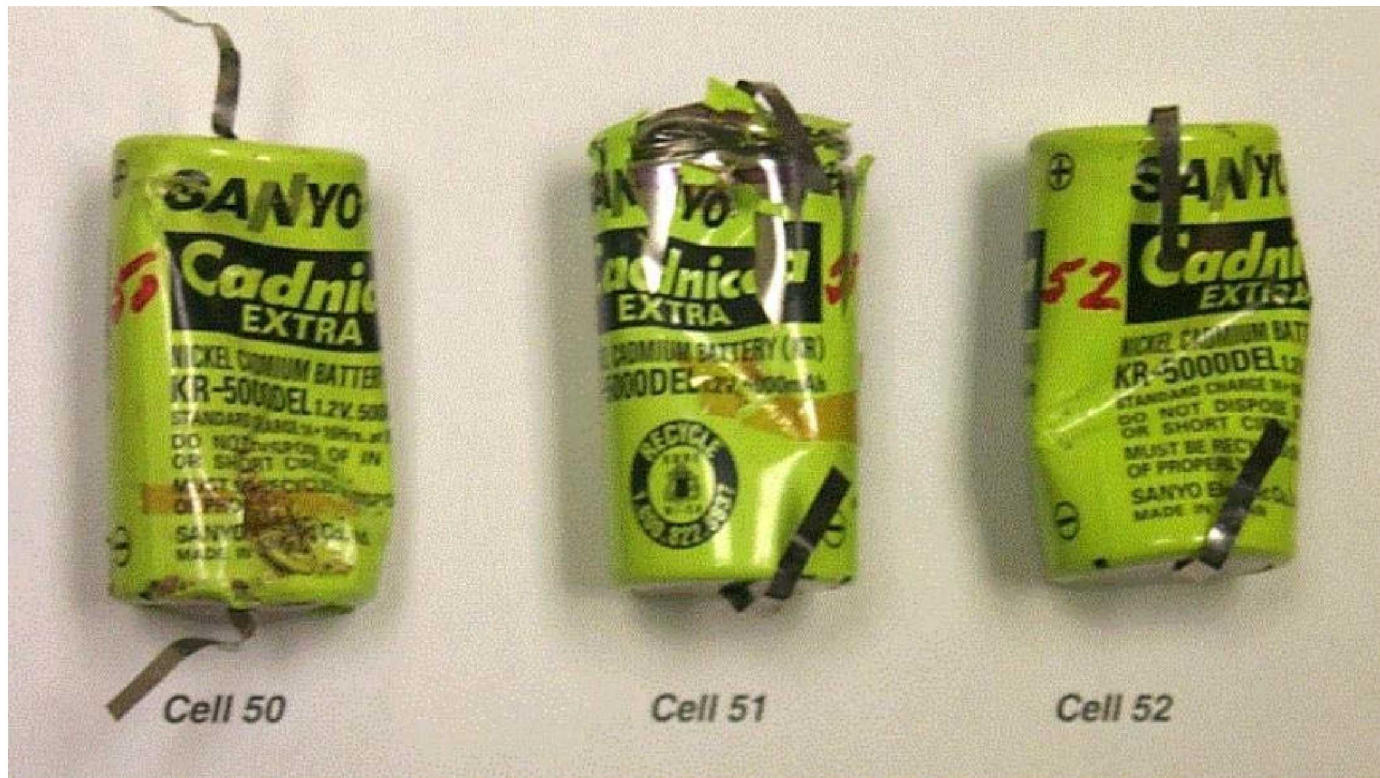


A good test method to determine a cell's safety tolerance



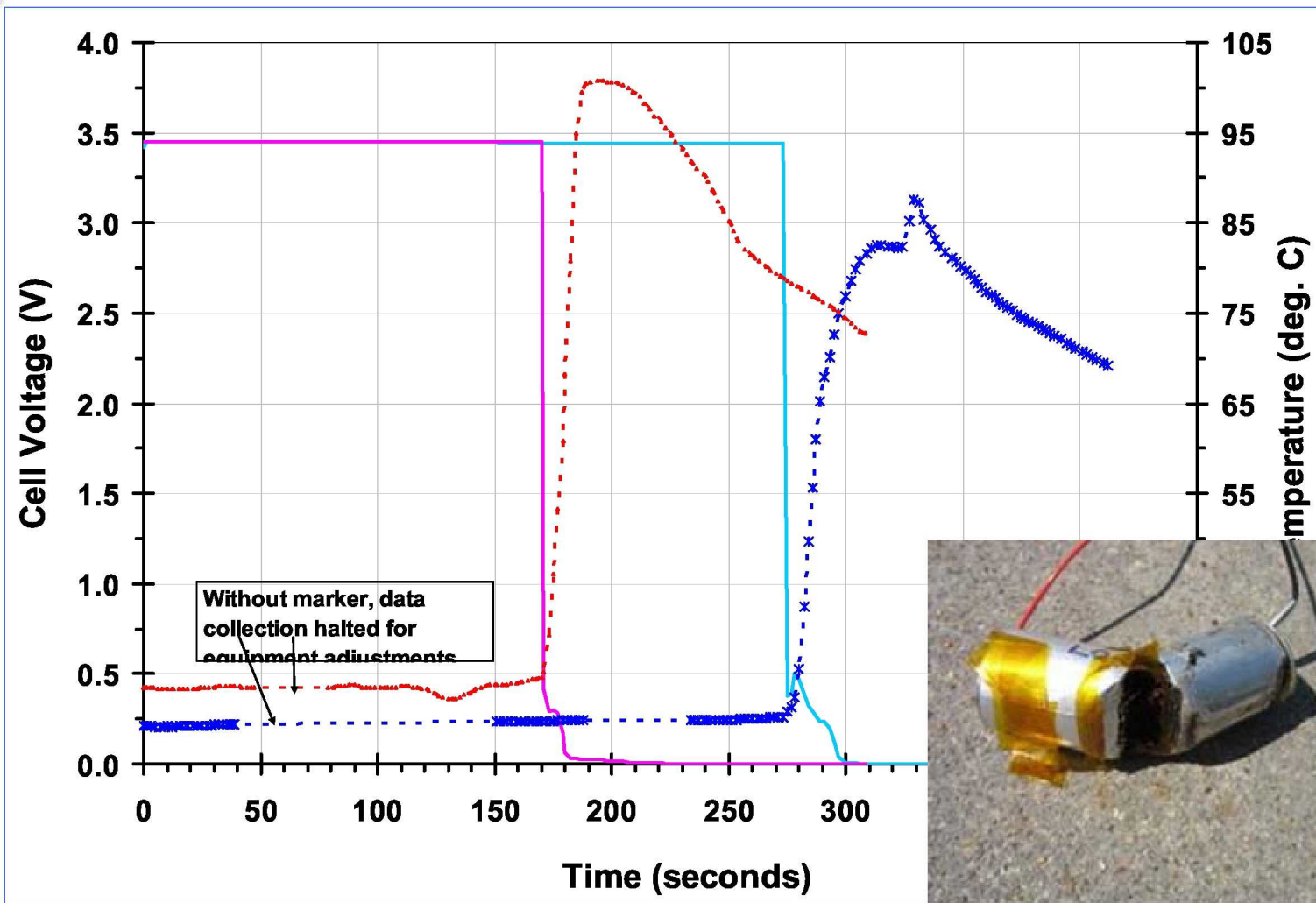
Simulated Internal Short Test on NiCd cell

- Cells show good OCV even when they are severely deformed.
- No violent explosion when the cells were crushed completely



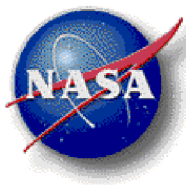


Simulated Internal Short for A123 LiFePO₄ Cell



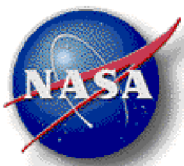
Can is not robust and breaks after voltage drop.

Judith Jeevarajan/NASA-JSC



NASA-JSC Procedure of Screening for Internal Shorts

- Flight batteries of battery chemistries **tolerant** to internal shorts undergo workmanship vibration.
- Flight batteries of battery chemistries **intolerant** to internal shorts undergo vibration that is twice the level of the workmanship vibration.
- Batteries from the flight lot are qualified to a higher level for longer durations under a qualification program to confirm that the batteries can handle the flight vibration.



Vibration Tests

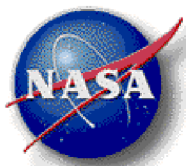
Vibration spectrum is very specific to flight applications as it is based on the flight environment. (JSC 20793)

Vibration spectrum for flight batteries with chemistries that are tolerant to internal shorts; one minute in each axis (x, y and z)

FREQ (Hz)	ASD (G ² /Hz)	dB/OCT	Grms
20.00	0.010000	*	*
80.00	0.040000	3.01	1.22
350.00	0.040000	0.00	3.51
2000.00	0.007000	-3.01	6.06

Vibration spectrum for flight batteries with chemistries that are intolerant to internal shorts; one minute in each axis (x, y and z)

FREQ (Hz)	ASD (G ² /Hz)	dB/OCT	Grms
20.00	0.028800	*	*
40.00	0.028800	0.00	0.76
70.00	0.072000	4.93	1.43
700.00	0.072000	0.00	6.89
2000.00	0.018720	-3.86	9.65



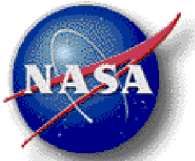
Qualification Vibration Spectrum

Vibration spectrum for flight batteries with chemistries that are tolerant to internal shorts; 15/5 minutes in each axis (x, y and

z)	FREQ (Hz)	ASD (G^2/Hz)	dB/OCT	Grms
	20.00	0.025000	*	*
	80.00	0.100000	3.01	1.94
	350.00	0.100000	0.00	5.55
	2000.00	0.017500	-3.01	9.58

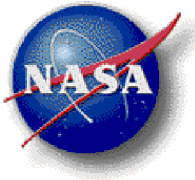
Vibration spectrum for flight batteries with chemistries that are intolerant to internal shorts; 15/5 minutes in each axis (x, y and z)

FREQ (Hz)	ASD (G^2/Hz)	dB/OCT	Grms
20.00	0.057600	*	*
40.00	0.057600	0.00	1.07
70.00	0.144000	4.93	2.02
700.00	0.144000	0.00	9.74
2000.00	0.037440	-3.86	13.65



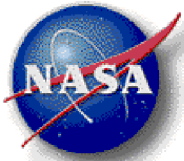
Vibration Test Pass / Fail Criteria

- 100 % of flight batteries undergo vibration screening tests to screen for internal shorts.
- Pass/Fail: Difference in OCV pre and post-vibe shall be less than 0.1 %; difference in capacity between pre and post-vibe shall not be greater than 5%. The second discharge value post-vibe is the one that is compared to the pre-vibe capacity value.
- All flight batteries undergo vacuum exposure for 6 hours with the same pass/fail criteria and an additional weight check; failures are more pronounced after vacuum exposure.



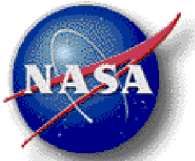
History of COTS Flight Batteries

- **Number of COTS camcorder BP 930 batteries flown since 2000**
 - **20 to 35 batts per mission**
 - Number of Lots purchased: 6 (50 to 200 batteries per lot)**
 - Failures during Flight Acceptance testing: In 2002, 5 batteries out of a lot of 160 failed post-vibration capacity check as well as had different settings on the circuit board and the whole lot was scrapped.**
 - Number failed on-orbit - 0**
- **Number of COTS Thinkpad Batteries**
 - **760XD -one lot – approximately 200 batteries – fly 7 to 9 batteries per mission**
 - **Number failed on-orbit with 0 V is 1; due to failed circuit board ; all cells showed very good OCV**
 - **A31P one lot- 800 batteries - fly 7 to 9 batteries per mission**
 - **Number failed on-ground or on-orbit - 0**
- **Number of COTS PDA Batteries with COTS prismatic cells**
 - **25 to 30; flown less than 5**



UL and IEC

- **In early October, this method was proposed at the IEC STP working group.**
 - The method is being reviewed and commented on by the members at this time.
- **Since the UL method is similar to NASA-JSC method, discussions are being held on collaboration for optimizing this method.**
- **The BAJ method is also under consideration. Although the BAJ method is an excellent method, it is not one that can be adopted by everyone. Only cell manufacturers can carry out that test.**
 - Pros: All Japanese cell manufacturers are being held to this standard and cannot place their li-ion cells in the market if they do not pass this test. Design changes have already been made in the cells, as they were aware of this being imposed, a year ago.
 - Cons: Several companies have been created to do this specific test in Japan and China. If the test is not performed in a consistent manner, there could be more incidents in the commercial market.



Summary and Conclusions

- A method for simulation of internal shorts has been standardized at NASA-JSC.
- Method helps to differentiate between those battery chemistries that are tolerant and those that are intolerant to internal shorts.
- A method for screening of cells and batteries with chemistries that are intolerant to internal shorts has been used for almost a decade.
- No failures on-orbit with COTS li-ion batteries flown with the stringent ATP (acceptance test procedure) – includes government-furnished as well as payload batteries.



Acknowledgments

- All External as well as NASA-JSC Test Area teams